Gero JS and Brazier FMT (eds) (2002) *Agents in Design 2002*
Key Centre of Design Computing and Cognition, University of Sydney, pp. 85-94.

# SITUATED AGENT COMMUNICATION FOR DESIGN

UDO KANNENGIESSER and JOHN S GERO
*Key Centre of Design Computing and Cognition*
*University of Sydney Australia*

**Abstract.** This paper outlines an approach to communication among design agents in a multi-agent environment. This approach is founded on the concepts of situatedness from cognitive science and is an extension of traditional multi-agent communication.

## 1. Introduction

There has been a growing interest over the last few years in systems in which multiple agents attempt to cooperatively perform a common task. The fundamental advantage of the multi-agent system (MAS) approach can be seen in its modularity and its ability to work in complex environments. There is a wide variety of applications in which multi-agent systems have successfully been used (Jennings et al. 1998). The benefits of employing multiple agents have also been recognised in the design domain, which is a setting characterised by complex interactions of collaborating actors specialised in particular fields of expertise and often having conflicting interests. Some design systems based on multiple cooperative agents have been developed (Campbell et al. 1998, Grecu and Brown 2000).

Every collaborative system based on locally acting entities with only bounded perspectives has to deal with the issue of how a globally consistent behaviour can be achieved. Strictly pre-defined approaches to this problem (e.g. hierarchical organizations of agents) have been efficient in predictable environments, but are too simplistic to be applied in more open task domains. Most MAS work advocates the use of more flexible ways to achieve agent collaboration. This has opened up a number of research issues in multi-agent systems (Sycara 1998), most of which focus on conceptual and practical aspects of inter-agent communication and negotiation. Many of the assumptions and results of these studies have also been adopted in research in design agents. This paper argues that a one-to-one mapping of the current MAS approach to agent communication is not appropriate in the design domain, and we will outline the beginnings of our work on agent communication that accounts for the situatedness of multi-agent designing.

## 2. Agent Communication in Design

Most MAS studies view the role of communication as a means for agents to coordinate their actions through a process frequently referred to as negotiation (Sycara 1988). More specifically, agents during negotiation communicate proposals and counterproposals to finally come to an agreement. Communication thus serves as a transmitter of representations of intentions between different agents. This has led to the development of a number of agent communication languages (ACLs) and communication protocols (Dignum and Greaves 2000), which define some basic conventions and specifications for the elements and the structure of single messages as well as of sequences of messages.

It has been largely acknowledged that for agents to understand each other's ACL messages they must in some way share a common body of background knowledge or ontology (Gruber 1993) to ensure that the communicated concepts have a uniform meaning for each agent. As multi-agent systems typically unify agents specialised in different domains, each of which deals with different knowledge and different vocabularies, this is not a trivial condition. This is true especially in the context of design projects, where experts of various specialised domains, e.g. architecture, structural engineering, construction, etc., need to collaborate. In most MAS work, the issue of multiple ontologies has been approached by specifying a common ontology that can be used to translate from one ontology to the other. This common ontology is a formal schema pre-defined and encoded by the MAS developer and has been used in a number of static MAS applications concerned with problem solving in well-defined solution spaces.

Communication has also been a matter of interest in collaborative and multidisciplinary design research (e.g. Cutkosky et al. (1993), Shen and Barthès (1996)). Approaches that focus on the exchange of product data among the different computational tools involved in product development have commonly been categorised as product modelling. They all use a neutral data schema to make the different computational processes interoperable and thus are comparable to the ontology approach to communication in multi-agent systems. One recent example is the International Alliance for Interoperability (IAI), that has pre-defined a product data schema consisting of Industry Foundation Classes (IFCs) (IAI 2000) represented in EXPRESS (ISO 1994). This has the effect that all the resulting product models are static, i.e. it is not possible to design novel products without first deciding on and representing its components in EXPRESS otherwise there will be no interoperability between systems using different data and different data representations. Although this approach has been recognized as a restriction for designing (Ramscar et al. 1996; Turk 2001), it did not stop recent developments in multi-agent design systems (e.g. McAlinden et al. (1998)) adopting the static world assumption underlying this view on agent communication.

While these approaches mainly deal with concepts of structure, there are increasing efforts in enriching design ontologies to include also function and behaviour (Umeda and Tomiyama 1997; Szykman et al. 2001). Although this has obvious benefits, it aggravates the problem of imposing a static world onto designing. All ontologies that have been developed to date for multi-agent design systems do not account for design concepts being grounded in the individual experience of the agent (Gero and Kannengiesser 2002). If multi-agent systems are to be employed to support designing, we need different models of agent communication than those based on static, pre-defined ontologies.

## 3. Situatedness and Communication

The notion of situatedness has been introduced in design research (Gero 1998) to capture a range of phenomena observed in studies of designers, which traditional models of designing fail to address. Specifically, situatedness is used to account for the open environment in which designing by (human or computational) agents takes place. It is based on the view that "where you are when you do what you do matters", i.e. an agent does not simply react reflexively in its environment but uses its interpretation of its current environment and its knowledge to produce a response (Clancey 1997). Schön and Wiggins (1992) have identified designing as a process of "interaction of making and seeing". As a consequence the agent can be exposed to different environments (external as well as internal to the agent) and produce appropriate responses. The agent's knowledge is thus grounded in its interactions with the environment rather than encoded by a third party.

A number of situated design agents have recently been implemented (Kulinski and Gero 2001; Smith and Gero 2001). However, the focus of these agent developments is restricted to single agents, i.e. the agents interact with environments that do not contain other agents. As a consequence, no form of communication between agents has been needed in these studies.

An account of multiple computational agents grounding internal representations through their interaction with one another has been provided by the Artificial Life-inspired work of Steels (Steels 1998). The agents in his experiments have been able, after a number of simulation runs, to emerge a common ontology. However, this approach does not address how individual agents having different backgrounds and ontologies can communicate in an intelligible and efficient way.

Communicating has been described as a form of action (Austin 1962), performed by an agent to modify the internal environment of the agent it communicates with via the generation of external representations. As a special kind of an agent's interaction with its environment, we see communication as a situated act where all representations are generated for the particular purpose in the current situation, rather than just reproduced independently of their use. This includes an agent's external representations, generated for the purpose of being understood by a specific agent, as well as an agent's internal representations, generated for the purpose of understanding a specific agent. It conforms with the view that communicative action (i.e. the action of producing external representations in communication) is a form of social action, as its "subjective meaning takes account of the behaviour of others and is thereby oriented in its course" (Weber 1968). More precisely, it is "a social action oriented to reaching understanding" (Habermas 1984).

In our situated stance, the situation constructed by the agent performing and interpreting communicative actions needs to be taken into account in the process of generating (external and internal) representations, and this situation includes the interpretation of the external and internal environments of both agents. The following section describes the support for these considerations provided by cognitive studies of human language use.

## 4. Common Ground

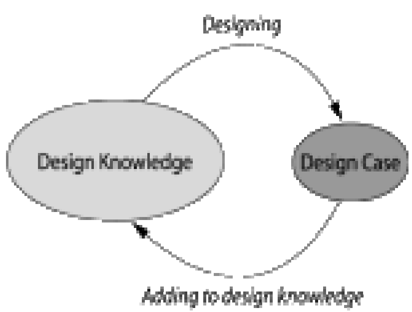
It is uncontroversial that in order to reach understanding, the content of a communicative action has to fit into some common context, otherwise communication is likely to fail resulting in agents not understanding or misunderstanding one another. This common context consists of mutual or shared knowledge about the context and has today most frequently referred to as "common ground".

Cognitive science has identified the notion of common ground as the key concept for successful communication. Common ground has been described as the set of presuppositions "any rational participant [in a conversation] is rationally justified in taking for granted, for example, by virtue of what has been said in the conversation up to that point, what all the participants are in a position to perceive as true, whatever else they mutually know, assume, etc." (Karttunen and Peters 1975). There has also been a number of approaches (e.g. Lewis (1969), Schiffer (1972)) to define common ground more formally. As stated by Clark and Marshall (1981), it can be expressed in the form of an infinite recursion[1]:

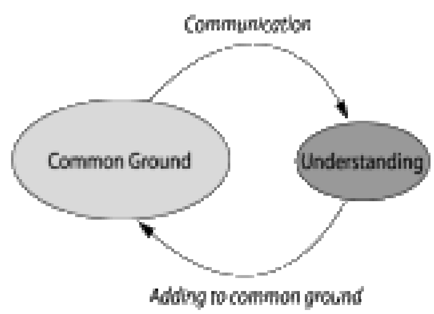
A and B mutually know that p = definition
(r) A knows that p and that r′.
(r′) B knows that p and that r.

The underlying reason behind this infinite recursion can be seen in common ground being an agent's first-person construction involving the other agent's first-person constructions (of common ground), which themselves involve the agent's first-person constructions, and so on. As most MAS models of communication do not have the notion of a first-person construction, they ensure mutual knowledge by directly encoding the presuppositions into both agents resulting in a common ontology. While this simplification avoids recursion, it pays the price of ignoring the grounded nature of the agents' knowledge.

As a consequence of being grounded, common ground accumulates during the course of the social interaction (Clark and Schaefer 1989). Figure 1 shows, in an analogy with designing, how every new understanding established through communication increases common ground; just as every new design case created through designing adds to design knowledge. Common ground, once established or increased, is then used to reach new understandings; just as design knowledge is required for producing new designs.




(a) Designing




(b) Communication

*Figure 1.* An analogy between (a) designing and (b) communication.

What an agent assumes to be its common ground with another agent is taken into account when producing or comprehending communicative actions (Clark and Murphy 1982; Fussell and Krauss 1989). This means,

[1] The theoretical necessity of this infinite recursion has been well illustrated by Clark and Marshall (1981).

for example, that an agent tailors its message to the specific addressee using its subjective view of common ground it shares with that addressee. In turn, the addressee uses its subjective view of common ground to comprehend the message in the same way as intended by the agent producing that message. This makes apparent that although common ground is a first-person construction it is also a social notion inextricably connected to the particular agent(s) involved in that common ground.

Common ontologies, even if they have been grounded (cf. Steels (1998)), lack this socially differentiated dimension. As a result, they are unable to adapt communication by producing different external and internal representations when different agents are involved. Such an adaptation, however, is needed in multi-agent systems in which heterogenous agents communicate. Common ground has the potential to bridge this gap, while preserving the situatedness of the agents and thus their autonomy in designing.

## 5. Integrating Common Ground into the Framework of a Situated Agent

We now want to bring together the concept of common ground and the architecture of a situated agent. Gero and Fujii (2000) have proposed a framework describing the processes involved in an agent's construction of its situation (when interpreting its environment). These include the construction stages of sensation, perception and conception (including its sub-stage of focussing on (or hypothesizing) goals). As common ground has been shown to be part of an agent's grounded experience or situation, it seems reasonable to model its construction in a way consistent with this framework. Figure 2 shows that the common ground between communicating agents may occur at four different levels (Traum and Dillenbourg 1998), mapping onto the above construction stages.

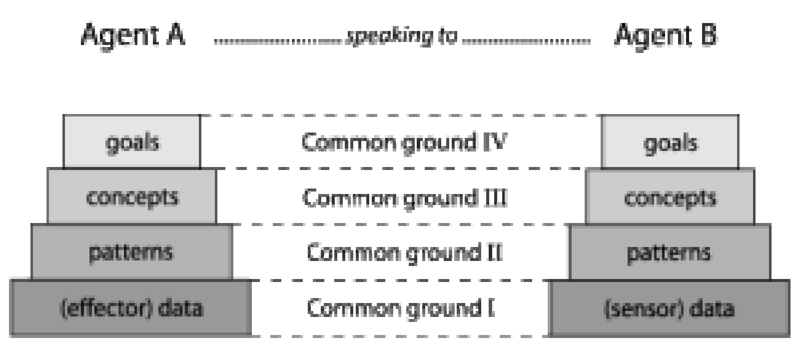



*Figure 2.* Four levels of common ground mapping onto the stages in the construction of an agent's situation.

On the first level, common ground I describes mutual knowledge where the output data generated by agent A's effectors correspond to the input data generated by agent B's sensors. On the second level, common ground II assumes mutual knowledge about like data patterns constructed in each agent. These patterns are a generalisation of the notion of percepts in interpretation. On the third level, common ground III refers to mutual knowledge about same concepts constructed in each agent. On the fourth level, common ground IV is about mutual knowledge about common goals. As goals are a particular type of concepts, common ground IV can similarly be seen as a particular type of common ground III.

The existence of common ground between communicating agents cannot be guaranteed. On the contrary, communication frequently has to deal with failures to reach a particular level of common ground. This includes failures of any one of the interpretation processes to produce an appropriate result (i.e. data, patterns, concepts or goals). A layered conception of common ground as in Figure 2 allows the identification of different kinds of these failures and is thus a condition for an agent to detect and repair any type of miscommunication. Paek and Horvitz (1999) have applied a similar model of common ground for human-machine collaboration, which is an area where communication has to cope with high levels of complexity and high risks of error.

In addition to the *a posteriori* repair of failures to reach common ground, an agent must attempt to avoid potential failures by considering the different levels of common ground within the respective processes of producing external or internal representations. This corresponds to the agent adapting both its message production and comprehension to the other agent. The differentiation of common ground into four levels specifies this adaptation more clearly, attributing one level of common ground to each process involved in communicating. It also extends existing approaches of agents constructing internal models of other agents' goals, such as proposed in the negotiation literature (e.g. Sycara (1988)), to also include those beliefs about other agents that are used to achieve the lower levels of common ground.

## 6. Discussion

This paper has proposed a shift from the current static view on agent communication towards one that is based on common ground and thus compatible with the concept of situatedness. We see this as a necessary cornerstone for applying multi-agent systems in open and dynamic environments such as design. MAS research in agent communication has generally taken common ground out of its cognitive context and transformed it into some static ontology to achieve interoperability.

This has been aimed at reducing processing effort but, as a consequence, has created the problem of interoperability by depriving the agents of the means of producing common ground.

A model of situated communication, more generally, has the potential to extend current standardisation approaches such as in the area of product modelling. This model would open up the possibility to use the MAS approach for the generation and representation of product data adapted to every specific purpose rather than just stored and reproduced according to a pre-defined schema. Our vision is a system of situated agents that self-organises a configuration of components to represent the product.

The integration of common ground into the agent architecture requires its further formalisation. The formal definition as described in Section 4 is not suitable from a computational viewpoint, as assessing common ground by means of infinite recursion would require infinite processing time and would not conform to the ease with which humans usually communicate (Clark and Marshall 1981). Here most cognitive studies suggest that an agent defaults to the assumption that its own knowledge is a good approximation for the other agent's knowledge. However, a unanimous model about how this defaulting takes place in the processes of message production and comprehension has not been developed yet. We are currently investigating different approaches to produce a sound foundation for the development, implementation and testing of an agent architecture that embodies common ground.

## Acknowledgements

This research is supported by a Sesqui Research and Development grant from the University of Sydney and by an International Postgraduate Research Scholarship.

## References

Austin JL: 1962, *How to do Things with Words*, Oxford University Press, Oxford.

Campbell MI, Cagan J and Kotovsky K: 1998, A-design: Theory and implementation of an adaptive, agent-based method of conceptual design, *in* JS Gero and F Sudweeks (eds), *Artificial Intelligence in Design'98*, Kluwer, Dordrecht, pp. 579-598.

Clancey WJ: 1997, *Situated Cognition,* Cambridge University Press, Cambridge.

Clark HH and Marshall CR: 1981, Definite reference and mutual knowledge, *in* AK Joshi and B Webber (eds), *Linguistics Structure and Discourse Setting*, Cambridge University Press, Cambridge, pp. 10-63.

Clark HH and Murphy GL: 1982, Audience design in meaning and reference, *in* JF Le Ny and W Kintsch (eds), *Language and Comprehension*, North-Holland Publishing Company, Amsterdam, pp. 287-299.

Clark HH and Schaefer EF: 1989, Contributing to discourse, *Cognitive Science* **13**, 259-294.

Cutkosky MR, Engelmore RS, Fikes RE, Genesereth MR, Gruber TR, Mark W, Tenenbaum JM and Weber JC: 1993, PACT: An experiment in integrating concurrent engineering systems, *Computer* **26**(1): 28-37.

Dignum F and Greaves M (eds): 2000, *Issues in Agent Communication*, Springer-Verlag, Berlin.

Fussell SR and Krauss RM: 1989, The effects of intended audience on message production and comprehension: Reference in a common ground framework, *Journal of Experimental Social Psychology* **25**: 203-219.

Gero JS: 1998, Conceptual designing as a sequence of situated acts, *in* I Smith (ed.), *Artificial Intelligence in Structural Engineering*, Springer, Berlin, pp. 165-177.

Gero JS and Fujii H: 2000, A computational framework for concept formation for a situated design agent, *Knowledge-Based Systems* **13**(6): 361-368.

Gero JS and Kannengiesser U: 2002, The situated Function-Behavior-Structure framework, *in* JS Gero (ed.), *Artificial Intelligence in Design'02,* Kluwer, Dordrecht, pp. 89-104.

Grecu DL and Brown DC: 2000, Expectation formation in multi-agent design systems, *in* JS Gero (ed.), *Artificial Intelligence in Design'00*, Kluwer, Dordrecht, pp. 651-671.

Gruber TR: 1993, A translation approach to portable ontologies, *Knowledge Acquisition,* **5**(2): 199-220.

Habermas J: 1984, *The Theory of Communicative Action*, Vol. 1, Beacon Press, Boston.

IAI: 2000, *Industry Foundation Classes,* International Alliance for Interoperability, http://eande.lbl.gov/btp/iai/copyright_ifc2x.html.

ISO: 1994, *ISO 10303-11 Product Data Representation and Exchange – Part 11: Description methods: The EXPRESS language reference manual*, International Standards Organization, Geneva, Switzerland.

Jennings NR, Sycara K and Woolridge M: 1998, A roadmap of agent research and development, *Autonomous Agents and Multi-Agent Systems* **1**(1): 175-306.

Karttunen L and Peters S: 1975, Conventional implicature of Montague grammar, *in* C Cogen, H Thompson, G Thurgood, K Whistler and J Wright (eds), *Proceedings of the First Annual Meeting of the Berkeley Linguistic Society*, University of California, Berkeley, CA, pp. 266-278.

Kulinski J and Gero JS: 2001, Constructive representation in situated analogy in design, *in* B de Vries, J van Leeuwen and H Achten (eds), *CAADFutures 2001,* Kluwer, Dordrecht, pp. 507-520.

Labrou Y, Finin T and Peng Y: 1999, Agent communication languages: The current landscape, *IEEE Intelligent Systems* **14**(2): 45-52.

Lewis DK: 1969, *Convention: A Philosophical Study*, Harvard University Press, Cambridge.

McAlinden LP, Florida-James BO, Chao K-M, Norman PW, Hills W and Smith P: 1998, Information and knowledge sharing for distributed design agents, *in* JS Gero and F Sudweeks (eds), *Artificial Intelligence in Design'98*, Kluwer, Dordrecht, pp. 537-556.

Paek T and Horvitz E: 1999, Uncertainty, utility, and misunderstanding: A decision-theoretic perspective on grounding in conversational systems, *in* SE Brennan, A Giboin and DR Traum (eds), *Working Papers of the AAAI Fall Symposium on Psychological Models of Communication in Collaborative Systems*, pp. 85-92.

Ramscar M, Lee J and Pain H: 1996, A cognitively based approach to computer integration for design systems, *Design Studies* **17**(4): 465-483.

Schiffer S: 1972, *Meaning*, Clarendon Press, Oxford.

Schön D and Wiggins G: 1992, Kinds of seeing and their functions in designing, *Design Studies* **13**(2): 135-156.

Shen W and Barthès J-PA: 1996, An experimental multi-agent environment for engineering design, *International Journal of Cooperative Information Systems* **5**(1-2): 131-151.

Smith G and Gero JS: 2001, Situated design interpretation using a configuration of actor capabilities, *in* JS Gero, S Chase and MA Rosenman (eds), *CAADRIA 2001,* Key Centre of Design Computing and Cognition, University of Sydney, Sydney, pp. 15-24.

Steels L: 1998, The origins of ontologies and communication conventions in multi-agent systems, *Autonomous Agents and Multi-Agent Systems* **1**(2): 169-194.

Sycara KP: 1988, Resolving goal conflicts via negotiation, *in Proceedings of the Seventh National Conference on Artificial Intelligence (AAAI-88)*, St. Paul, MN, pp. 245-250.

Sycara KP: 1998, Multiagent systems, *AI Magazine* **19**(2): 79-92.

Szykman S, Fenves SJ, Keirouz W and Shooter SB: 2001, A foundation for interoperability in next-generation product development systems, *Computer-Aided Design* **33**(7): 545-559.

Traum DR and Dillenbourg P: 1998, Towards a normative model of grounding in collaboration, *in* W Heydrich and H Rieser (eds), *Proceedings of the ESSLLI98 Workshop on Mutual Knowledge, Common Ground and Public Information*, Saarbrücken, Germany, pp. 52-56.

Turk Z: 2001, Phenomenological foundations of conceptual product modelling in architecture, engineering and construction, *Artificial Intelligence in Engineering* **15**(2): 83-92.

Umeda Y and Tomiyama T: 1997, Functional reasoning in design, *IEEE Expert Intelligent Systems and their Applications* **12**(2): 42-48.

Weber M: 1968, *Economy and Society: An Outline of Interpretive Sociology*, Bedminster Press, New York.